

# Mapping Using NASA's Full-Waveform, Medium/High-Altitude, LVIS Lidar System

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# NASA's LVIS Sensor



## ■ NASA's LVIS sensor

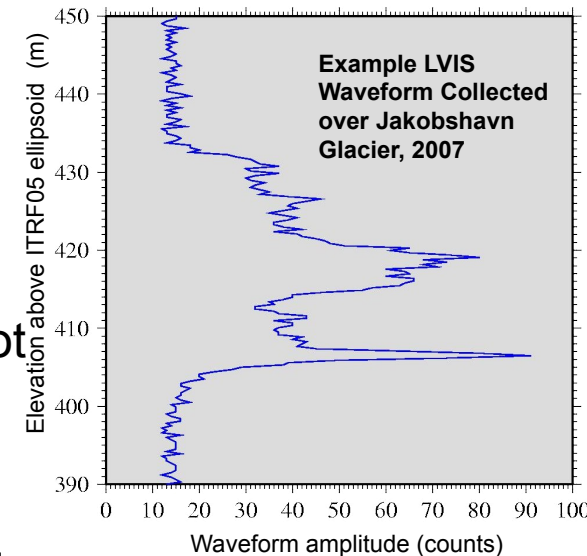
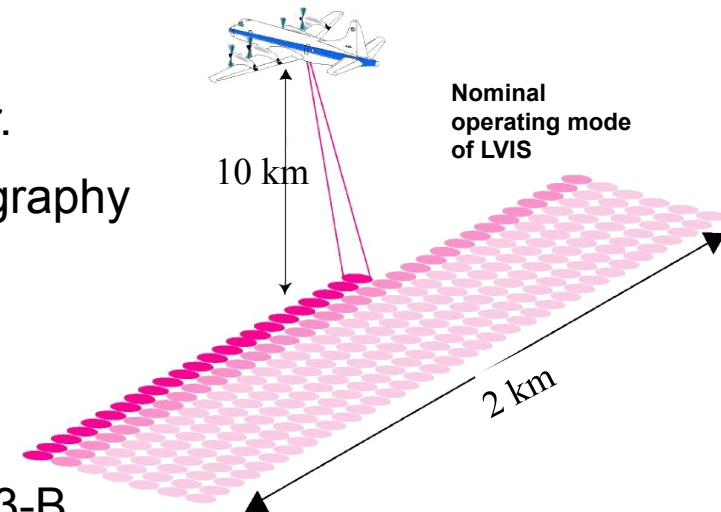
- ◆ Medium/high-altitude, waveform-recording lidar.
- ◆ Utilizes medium-sized footprints to image topography and surface structure.

## ■ Operational since 1997:

- ◆ Numerous missions for various investigations.
- ◆ Flown in Greenland in 2007, 2009 in NASA's P3-B.

## ■ LVIS capability for ICEBridge/Antarctica 2009:

- ◆ 2.75 km-wide swath with 20-25 m-wide footprints.
- ◆ 3 cm range precision
- ◆ 1-2m horizontal geolocation accuracy.
- ◆ Contiguous footprints along and across track.
- ◆ Tx&Return waveforms (10 bit, 1Gsamp/s) for each shot
- ◆ 2 detectors (90/10 split) eliminates saturation effect
- ◆ Quicklook data in 1-2 months, final data in <6 months.
- ◆ Enough link margin to penetrate through some clouds.





# LVIS: High-Altitude Lidar

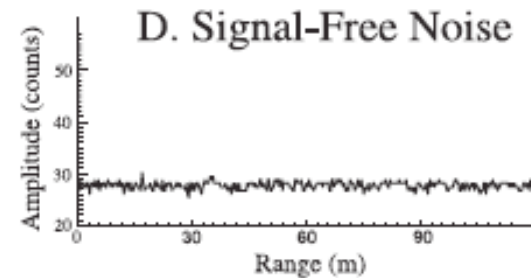
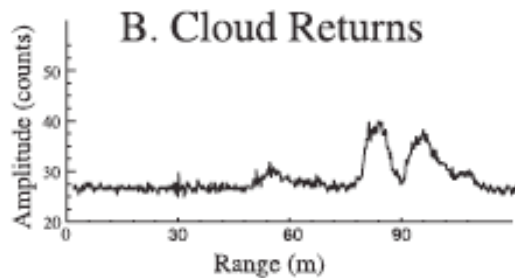
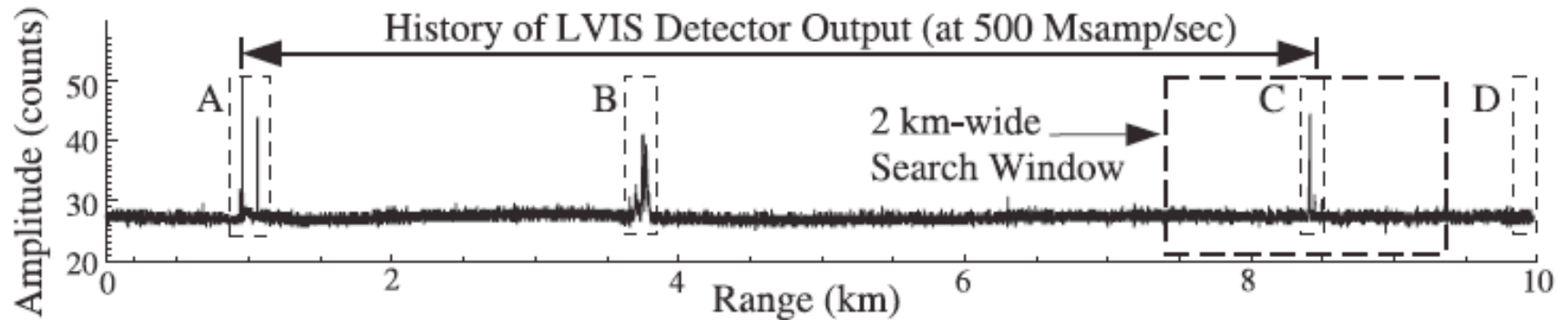
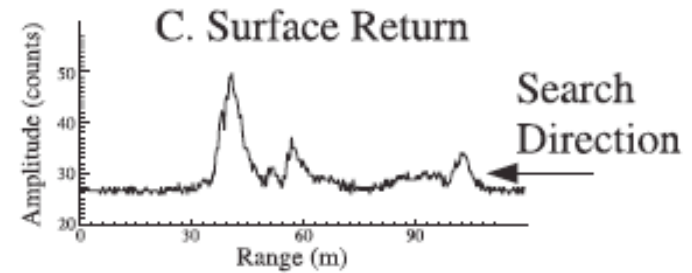
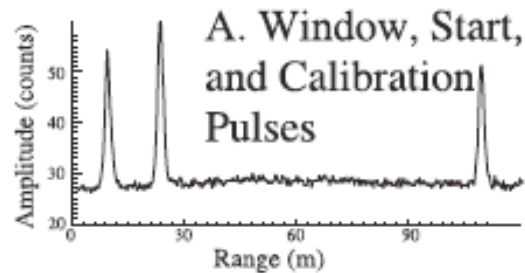


- NASA Laser Vegetation Imaging Sensor (LVIS)
- Used for prototyping spaceborne techniques and measurements
- 8-10+km flying altitude
- +-6 deg swath (i.e., 20% of flying altitude)
- Integrated GPS/INS Applanix 510
- Full waveform – captures all information footprint
- Data processed using VEGAS software
  - Variable Estimation and Geolocation System
- Data freely available at <https://lvis.gsfc.nasa.gov>
- Experiments: New England (Carbon Program), CA and MD (Biodiversity), Costa Rica (Carbon, Biodiversity, and Volcanoes), Arkansas (Biodiversity), Greenland, Gulf Coast (NOAA Gravity/Coastal Hazards)



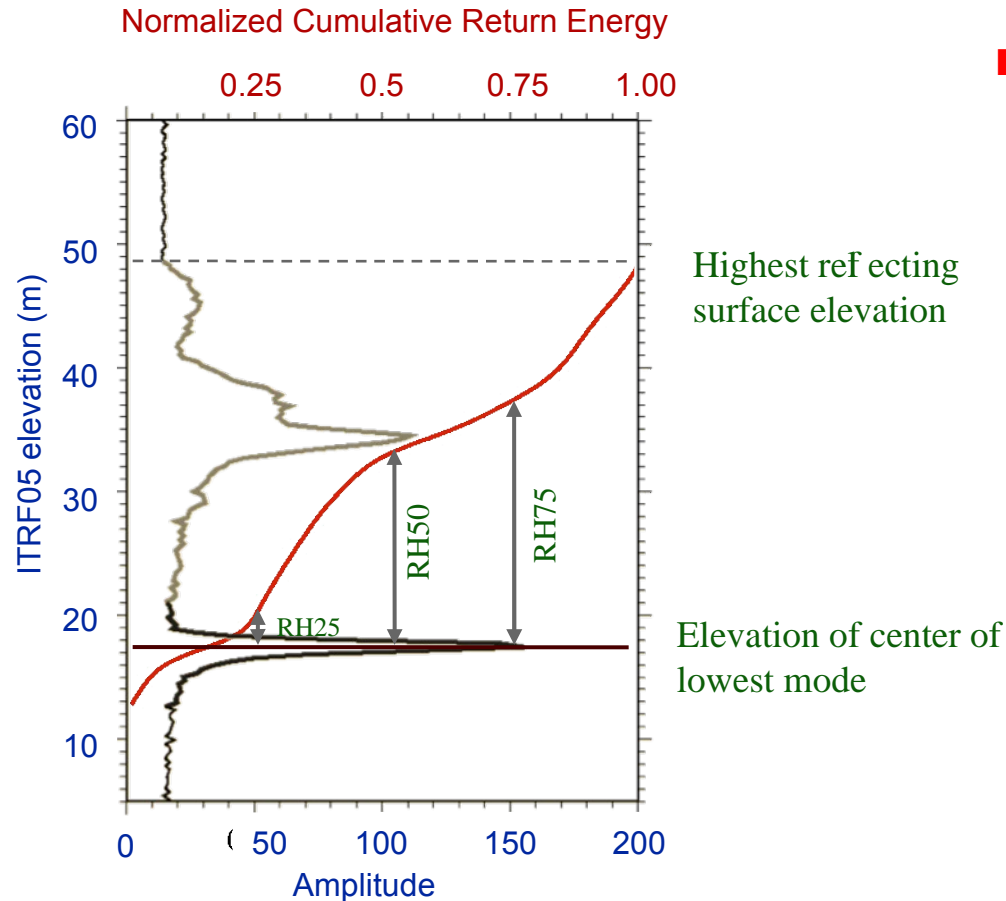


# LVIS Measurement Timeline





# LVIS Data products



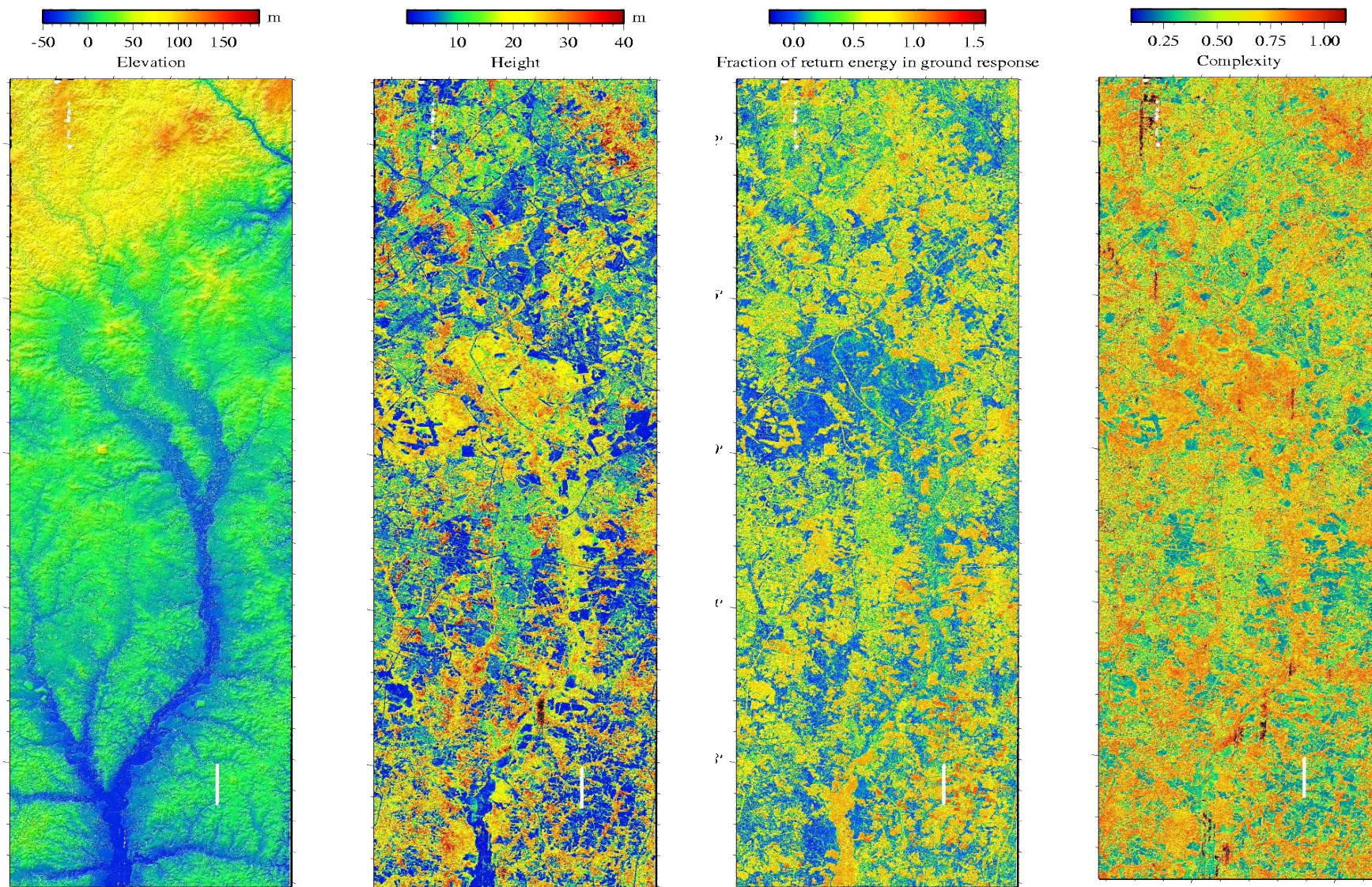
- Standard LVIS data products for each footprint are
  - ◆ Elevation of center of lowest mode in waveform (mean ground elevation)
  - ◆ Elevation of highest reflecting surface elevation
  - ◆ Vertical structure metrics (rh25, rh50, rh75) based on energy quartiles

- Data products available from <https://lvis.gsfc.nasa.gov>
  - ◆ Currently 100+ users

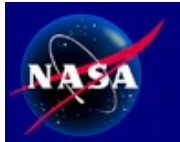




# Waveforms Yield Multiple Data Products

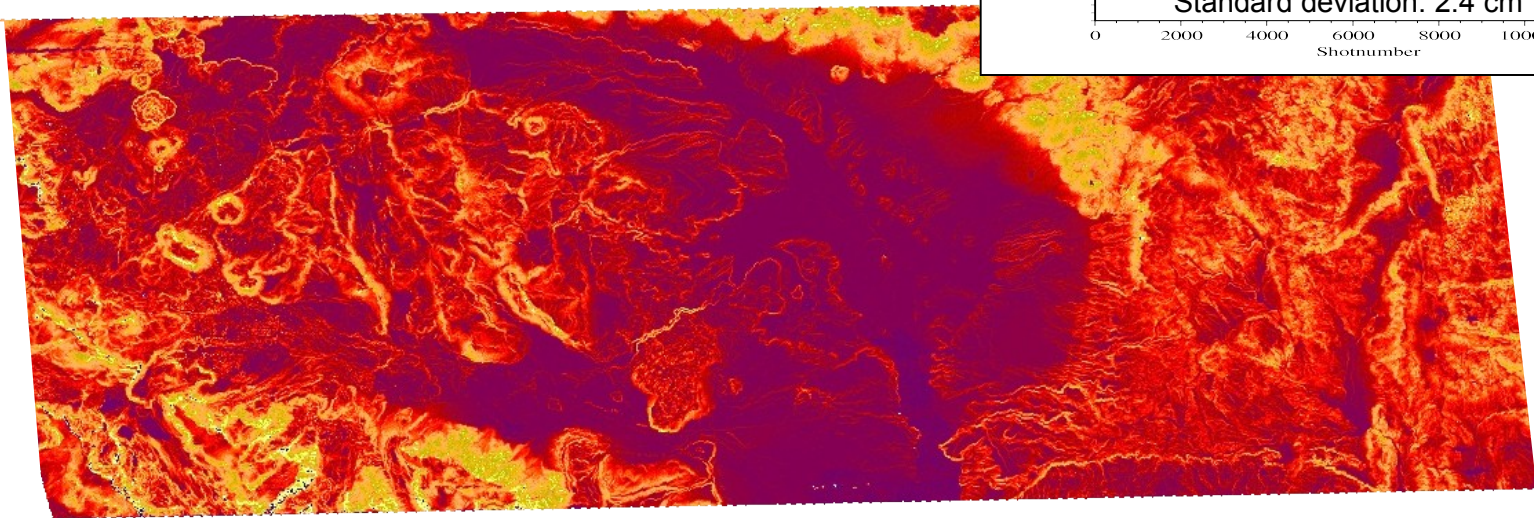
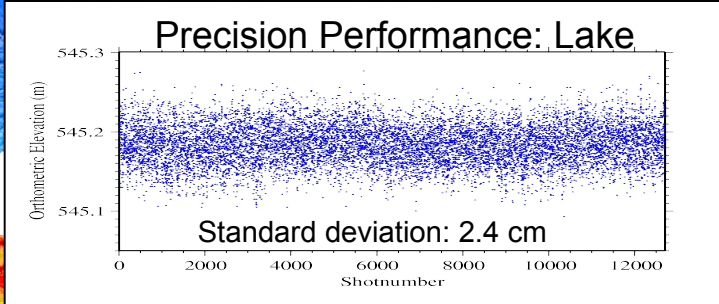
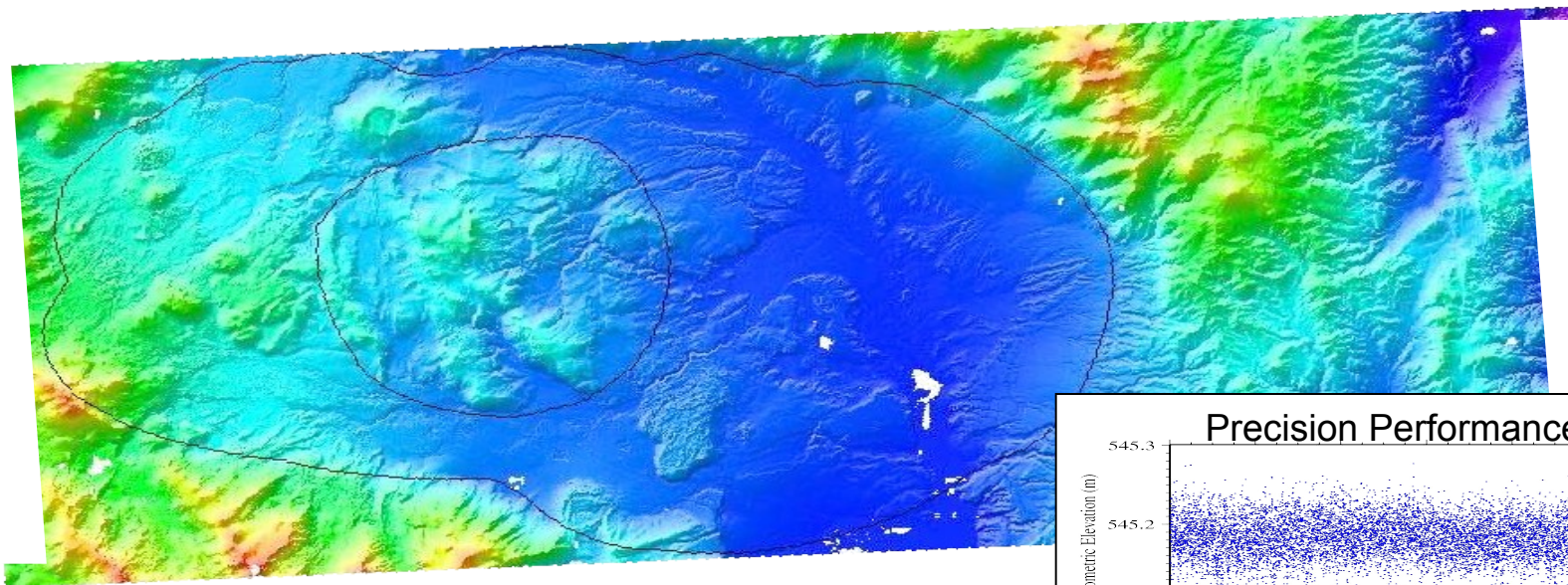






# Solid Earth Applications - Topography, Roughness

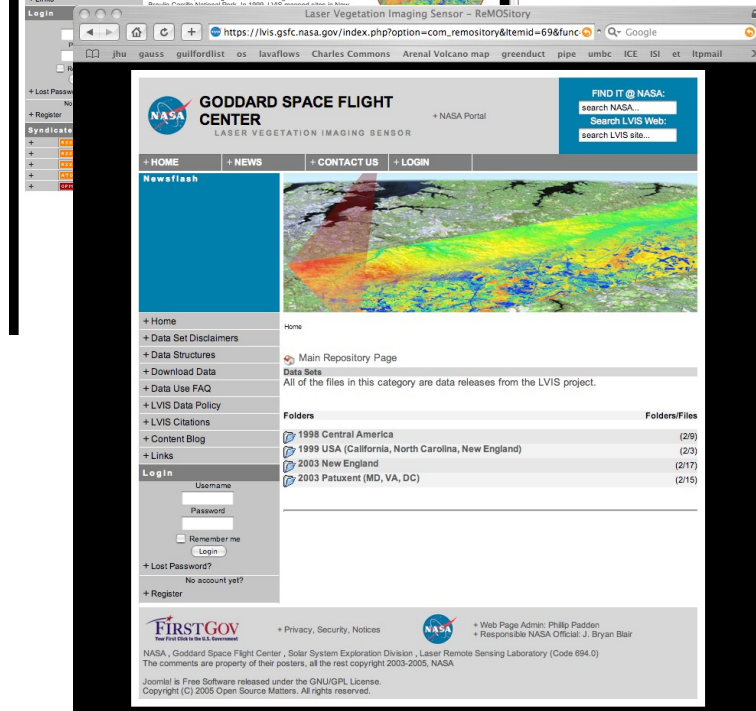
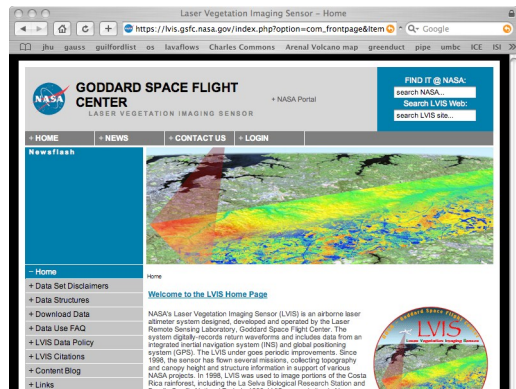
## Long Valley Caldera, CA







# LVIS Data Download



- LVIS data products are available to download from <https://lvis.gsfc.nasa.gov>
- Currently >150 registered users worldwide
- Latest data products distributed online as they become available

- ❖ Web site also contains useful information on using LVIS data
- ❖ Users can ask LVIS-specific questions if they have problems
- ❖ Frequently-updated FAQ section

Laser Vegetation Imaging Sensor - Data Structures

[https://lvis.gsfc.nasa.gov/index.php?option=com\\_content&task=view](https://lvis.gsfc.nasa.gov/index.php?option=com_content&task=view)

Home Data Structures

LVIS Data Structure (LDS) Descriptions  
[Data Use Tools v1.01](#)

Release Support Code	HTML Versions of Code	Description
lvis_release_v1_pro-1.01.zip	read_ice_v1.pro (v1.01) read_lge_v1.pro (v1.01) read_lgw_v1.pro (v1.01) struct_release_v1.pro (v1.01)	Structure definition and simple loading programs for IDL which will read the LVIS binary data distributions directly.
lvis_release_reader_v1.01.zip	lvis_release_reader_v1.01 (v1.01) lvis_release_structures 01.01A (v1.01)	C source code for converting binary released LVIS data into ASCII output. Command line options allow to cut by longitude and latitude boxes.

Overview of LVIS data products

[LDS v1.01](#)

Date Created: 2005/10/28

Byte Order:  
- All data items are Big Endian unless otherwise noted.

Reference Frame:  
- International Terrestrial Reference Frame (ITRF 2000) / WGS-84 Ellipsoid.

General Notes:  
- A release is comprised of two or more file types sharing a common origin. All files within the release have equal record numbers, and correspond to one another laser shot for shot. (i.e. record 1000 in the .lge file will be the same laser shot as record 1000 in the .ice file for a given data set)

LVIS Canopy Elevation (.lge) File Description:

Item	Byte Size	Format	Units	Item Description
fid	4	ulong		LVIS file identification
shotnumber	4	ulong		laser shot assigned during collection
lon	8	double	degrees	longitude of the highest detected return (degrees east)
lat	8	double	degrees	latitude of the highest detected return (degrees north)
z1	4	float	meters	elevation of the highest detected return (m) (i.e., z <sub>g</sub> ~ rh100 - see below)
Total	28			bytes per record

1 LVIS Ground Elevation / Total File Description:

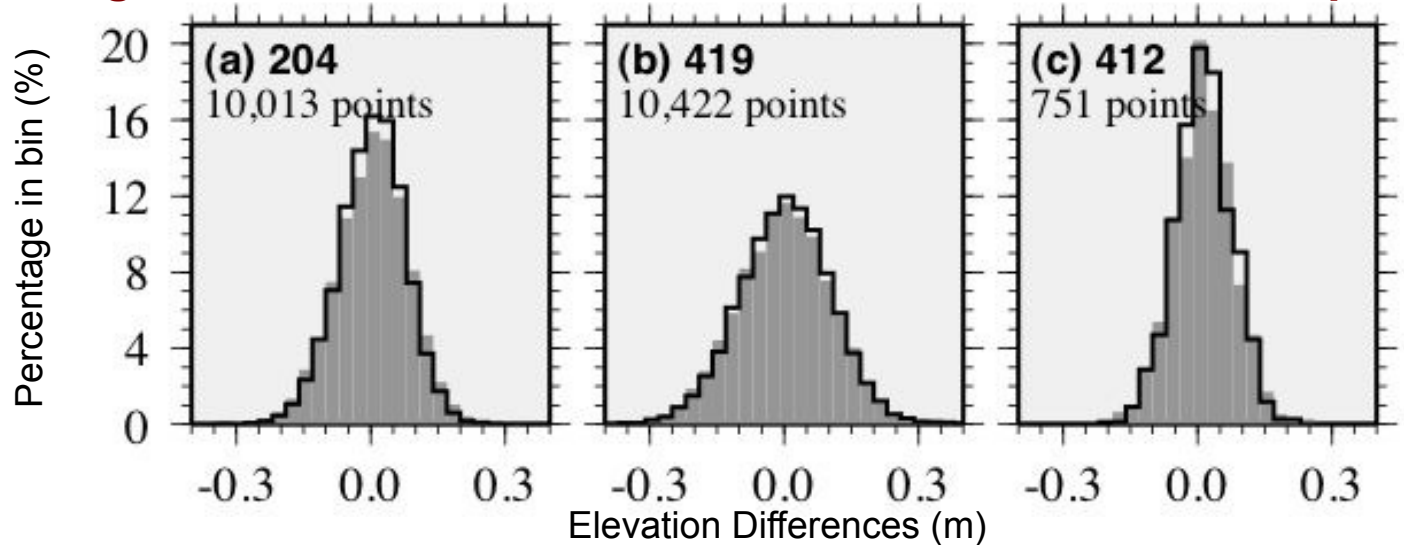




# LVIS Performance in Greenland, 2007

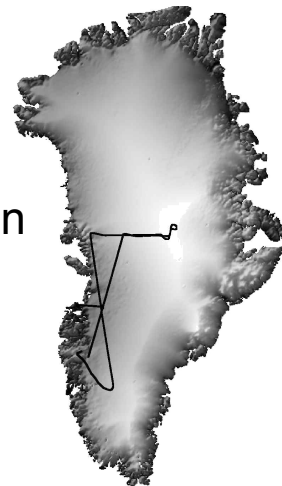


## Histograms of elevation differences at coincident LVIS footprints:



<b>Mean difference</b>	<b>0.00 m</b>	<b>0.00 m</b>	<b>0.01 m</b>
<b>Standard deviation (<math>1\sigma</math>)</b>	<b>0.08 m</b>	<b>0.11 m</b>	<b>0.06 m</b>

- LVIS data collected on 9/20/07 and 9/21/07 from ~27,000' in P3-B.
- Two ~850km long transects over ice sheet plus ~35 km long transect in the Summit area.
- Elevations differences between coincident footprints used to evaluate system performance.

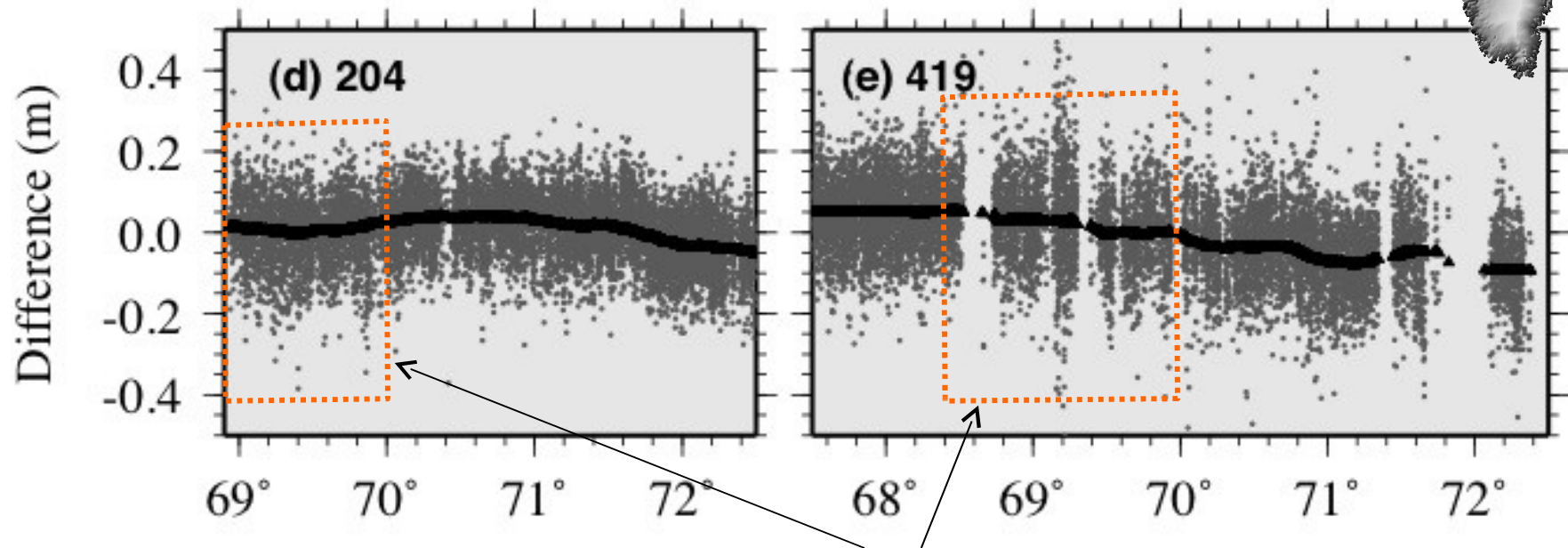
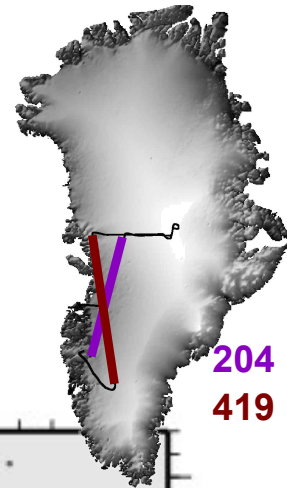




# Along-track Performance of LVIS Data in Greenland



- On average, elevation differences between coincident LVIS footprints had means of 0.0m, but along-transect variations of up to 5 cm occurred (likely caused by errors in the atmospheric model applied in the GPS trajectory calculations).



- *No obvious degradation in data precision over rough terrain (in this example, the feeder zone of Jakobshavn Glacier)*





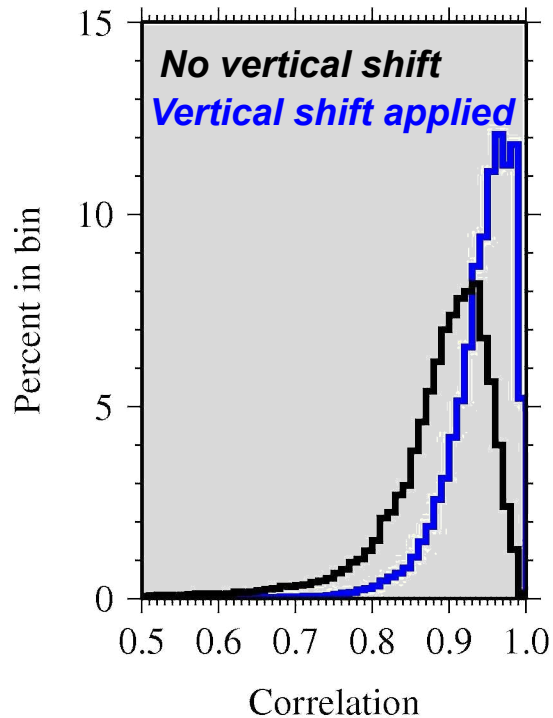
# SN08 Positioning Accuracy



- “Pseudowaveforms” generated at location of each LVIS footprint within  $\sim 10\text{km}^2$  area in Sierra Nevada National Forest also mapped by NCALM (Sept. 2008)

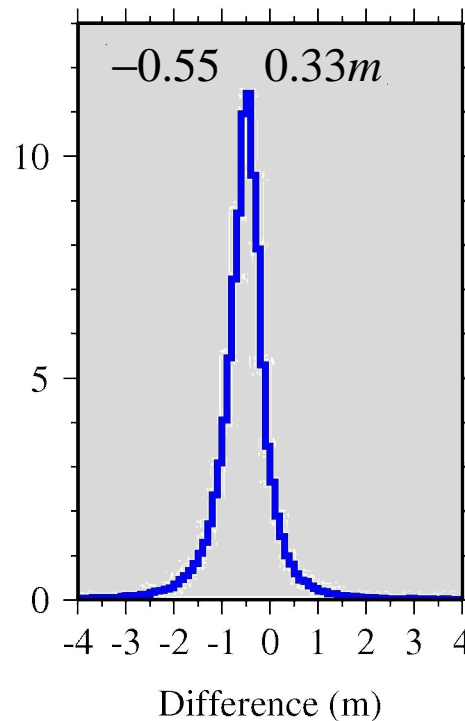


## Waveform Correlation

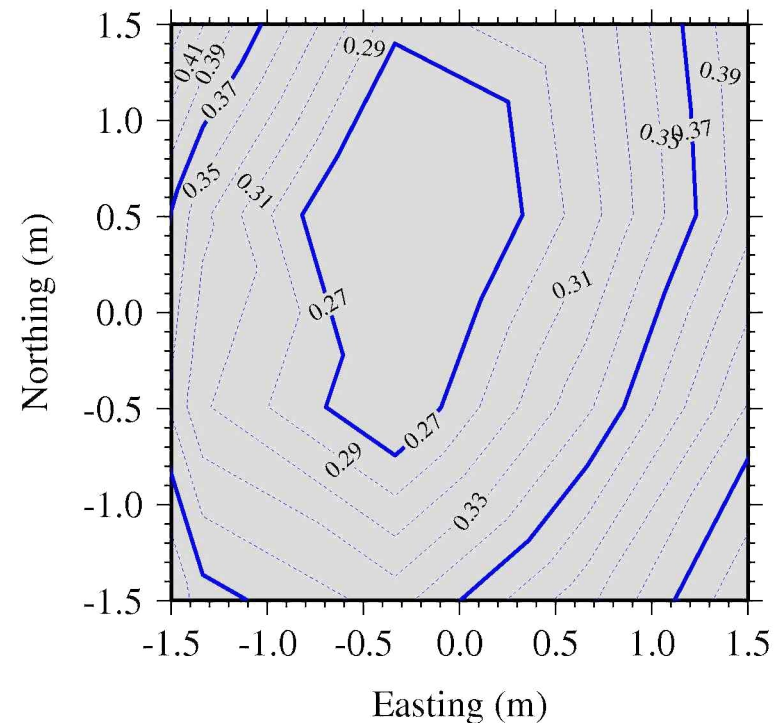


Mean=0.864, median=0.899  
Mean=0.940, median=0.952

## Vertical Shifts applied to NCALM data to maximize waveform correlation



## Horizontal Shifts applied to NCALM data to maximize waveform correlation



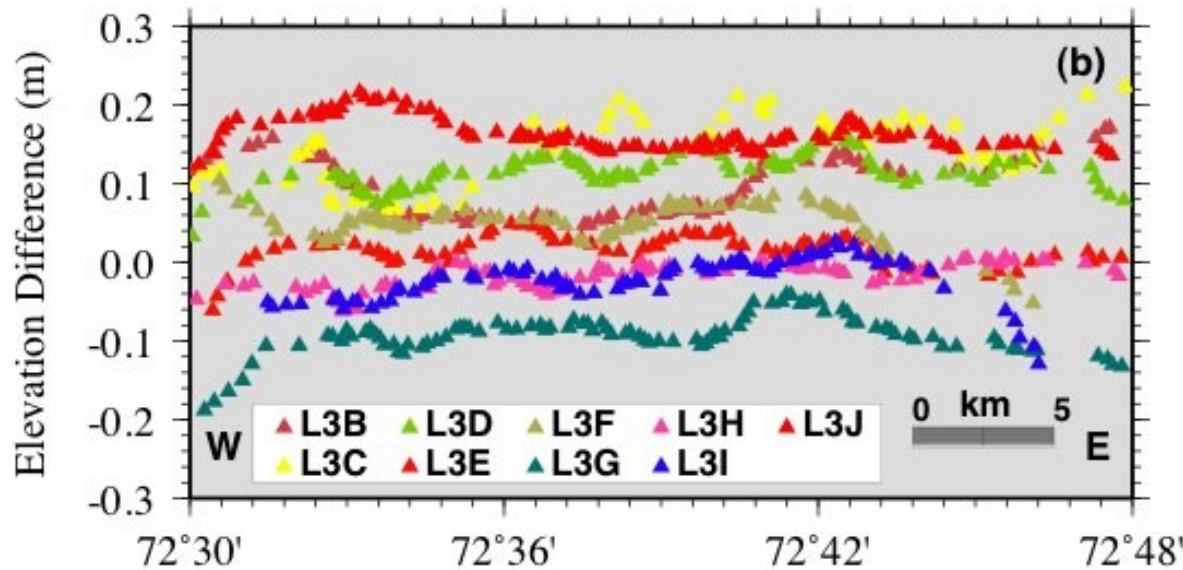
96,216 pts



# Comparison of 2007 LVIS Data and ICESat Data



- Comparing coincident LVIS (20m footprint) and ICESat (nominal 60m footprint) data in the Summit area.



Although there are offsets between the ICESat L3b-h observations and LVIS, the standard deviations of the differences are <7cm (except L3C).

ICESat ID	Date	# Points	Mean (m)	1 $\sigma$ (m)
L3B	3/23/05	71	0.08	0.06
L3C	6/22/05	70	0.10	0.13
L3D	11/23/05	86	0.10	0.07
L3E	3/23/06	87	0.00	0.06
L3F	6/26/06	78	0.05	0.06
L3G	11/26/07	96	-0.09	0.05
L3H	4/13/07	93	-0.02	0.06
L3I	11/4/07	80	-0.02	0.06
L3J	3/21/08	102	0.16	0.05

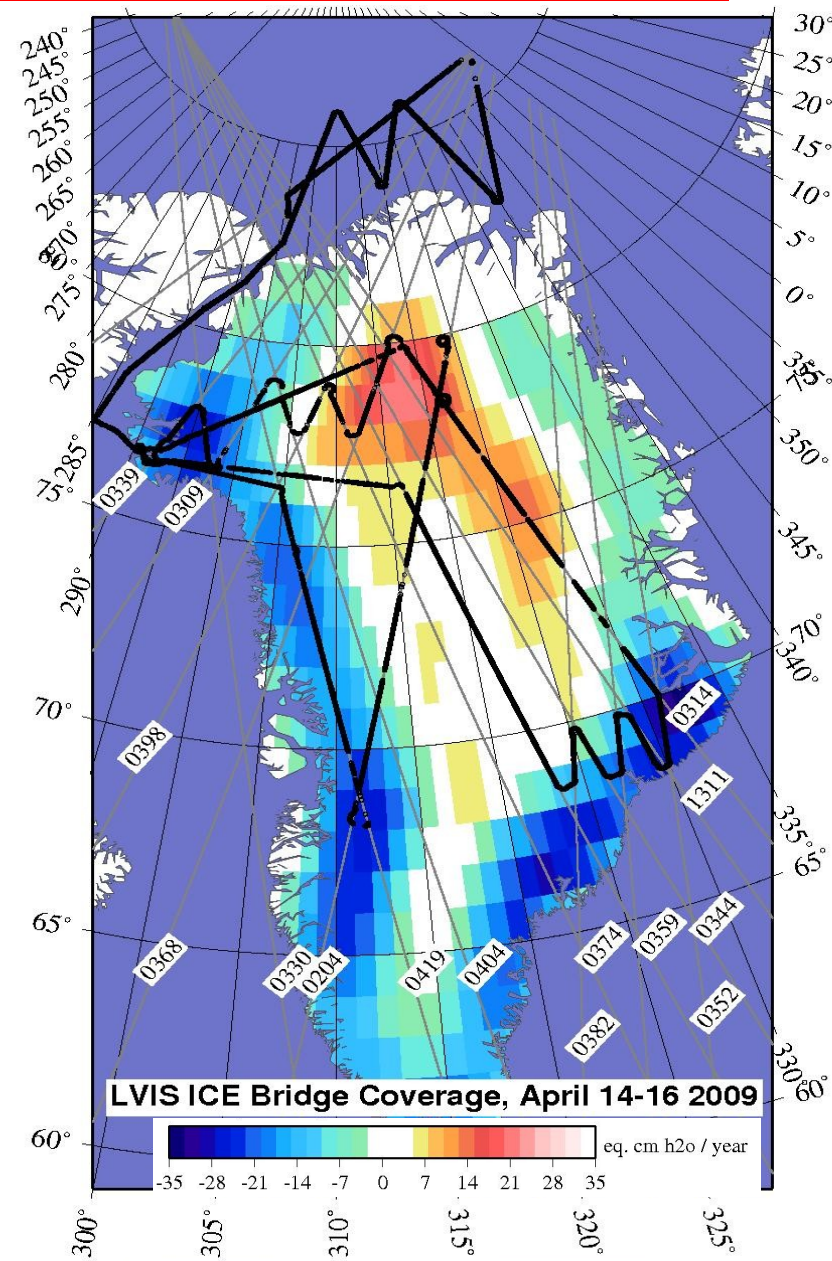




# ICEBridge Greenland Mapping, April 2009



- LVIS ICEBridge flights in Greenland:
  - ◆ 3 flights (1 sea-ice, 2 land-ice).
  - ◆ 25,000-27,000' altitude, 1-1.5km-wide swath, 20m footprints
  - ◆ Full transmit and receive waveform digitization (8 and 10bit)
  - ◆ ~5,900 lineal km of ICESat-I tracks imaged, including ~1200km using LVIS in 2007
  - ◆ ~3,900 lineal km of sea ice, including 600km of a recently-sampled ICESat track





# Status of Data



- Status of data
  - ◆ Quicklook processing completed
  - ◆ Issues identified for next release include improved trajectory precision and instrument parameter calibration, full implementation of 10-bit waveform data, integration of Ames IMU data with LVIS data
- Data will be released via Ivis web site (<https://lvis.gsfc.nasa.gov>)
- In addition to NSIDC/ICEbridge data release activities (Rick Weaver), proposal was recently submitted to NASA ACCESS Program with UNAVCO and NSIDC (PI: Chuck Meertens) to facilitate access of waveform lidar data to public (incl. ICESat data)

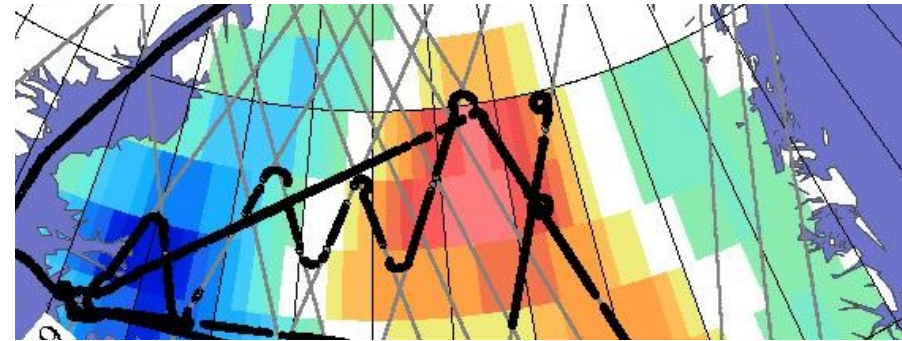




# Preliminary LVIS '09 Results: Precision

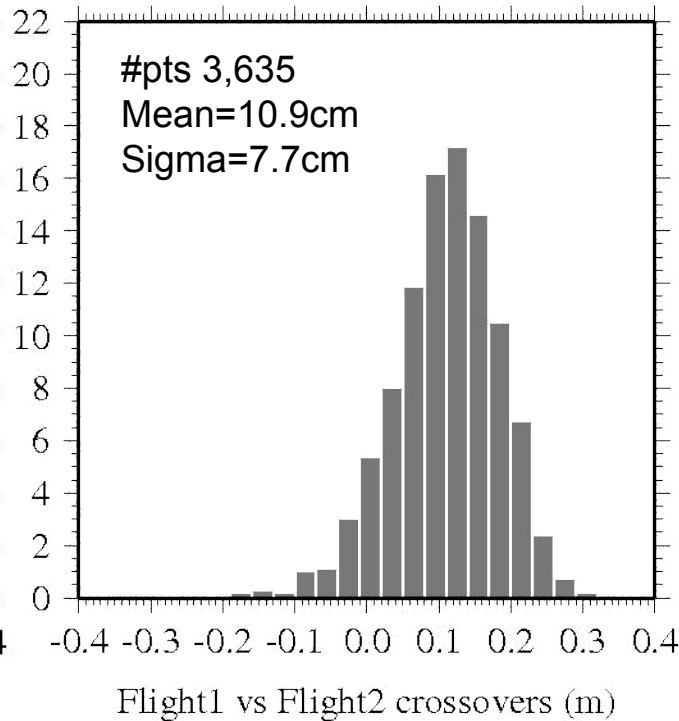
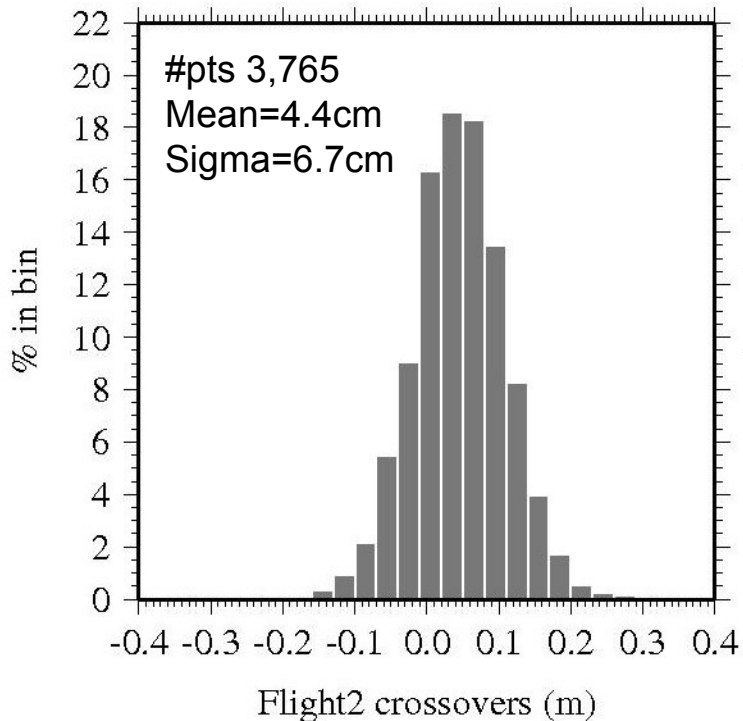


- Data Precision (LVIS vs. itself)
- Comparing coincident data from short (~250km) flight segments in northern Greenland (1m search radius)



Day2 vs. Day2

Day1 vs. Day2



- Results encouraging -measurement sigma < 8cm
- Mean offset is trajectory related
  - ✧ v2 of trajectories being calculated

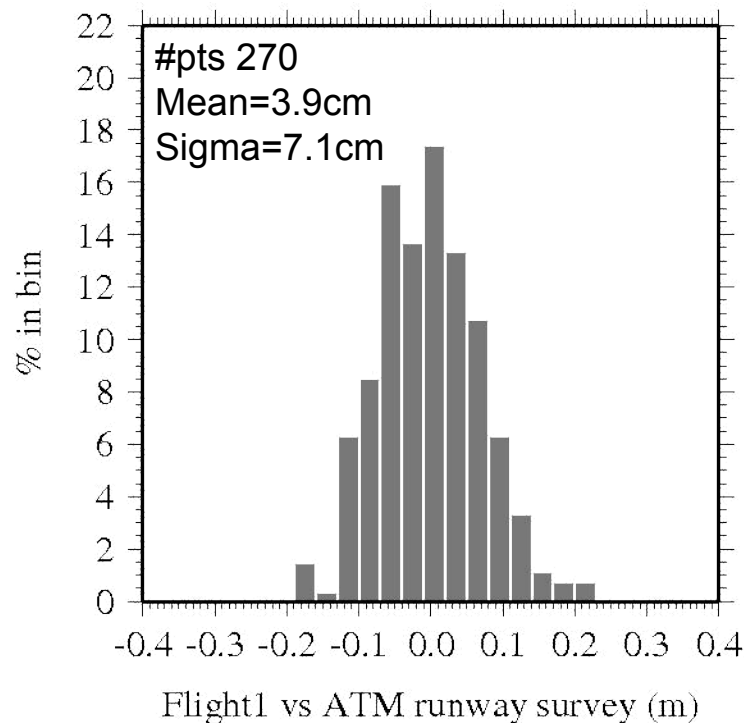


# Preliminary LVIS '09 Results: Accuracy

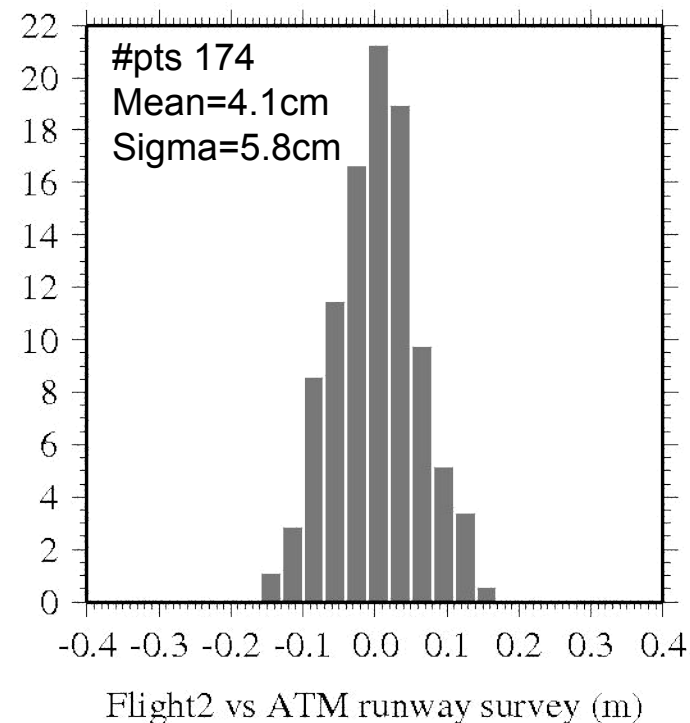


- Using Thule GPS runway survey (courtesy E. Frederick/ATM)
- Closest GPS point to center of LVIS footprint extracted and elevations compared (1m srاد)

## Day1 vs. GPS survey



## Day2 vs. GPS survey



- **Preliminary results encouraging - sigma is  $\leq 7$ cm**

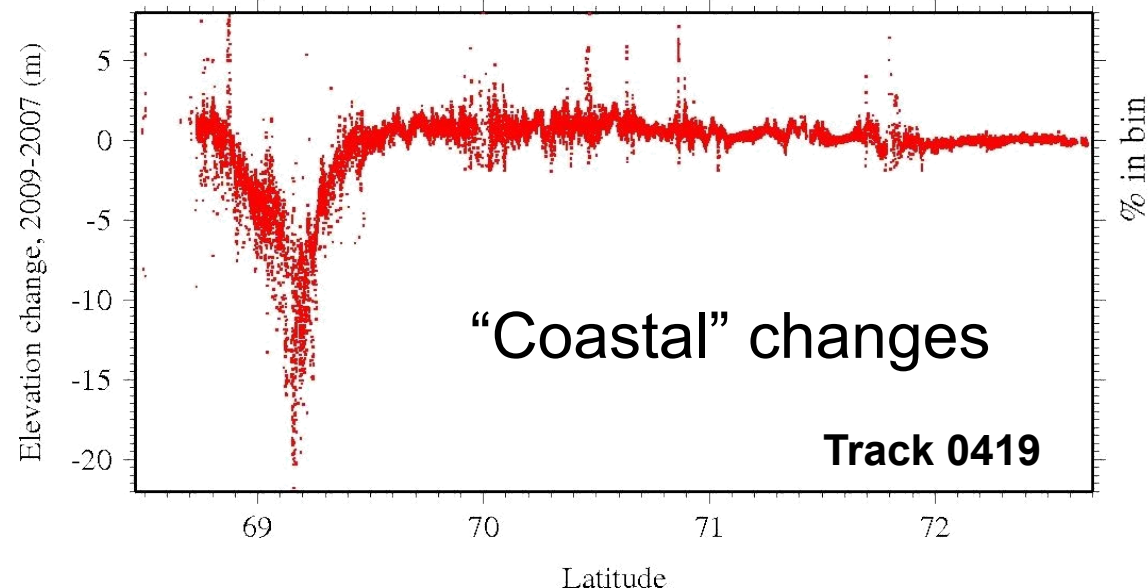
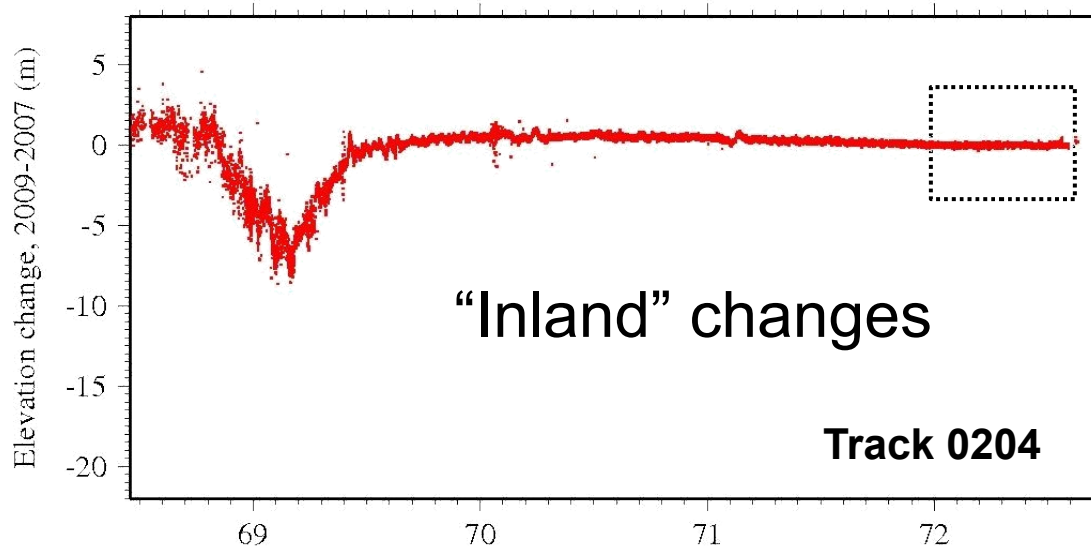
✧ Mean difference being fed back into parameter estimation process



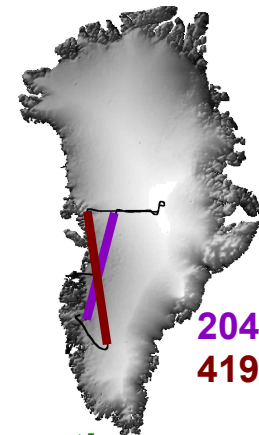
# Preliminary LVIS '09 Results: vs. 2007 data



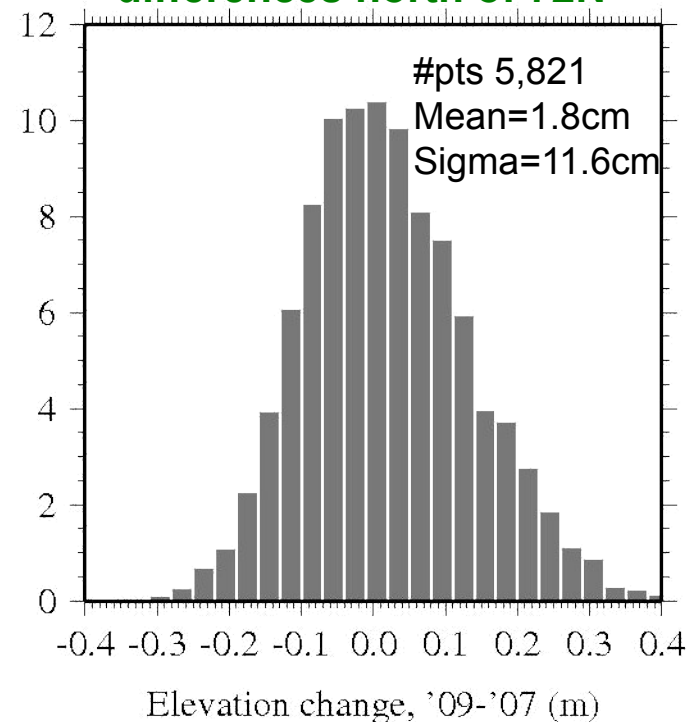
## LVIS 2009 – 2007 Elevations



■ LVIS 2007 and 2009 footprints within 1m of each other



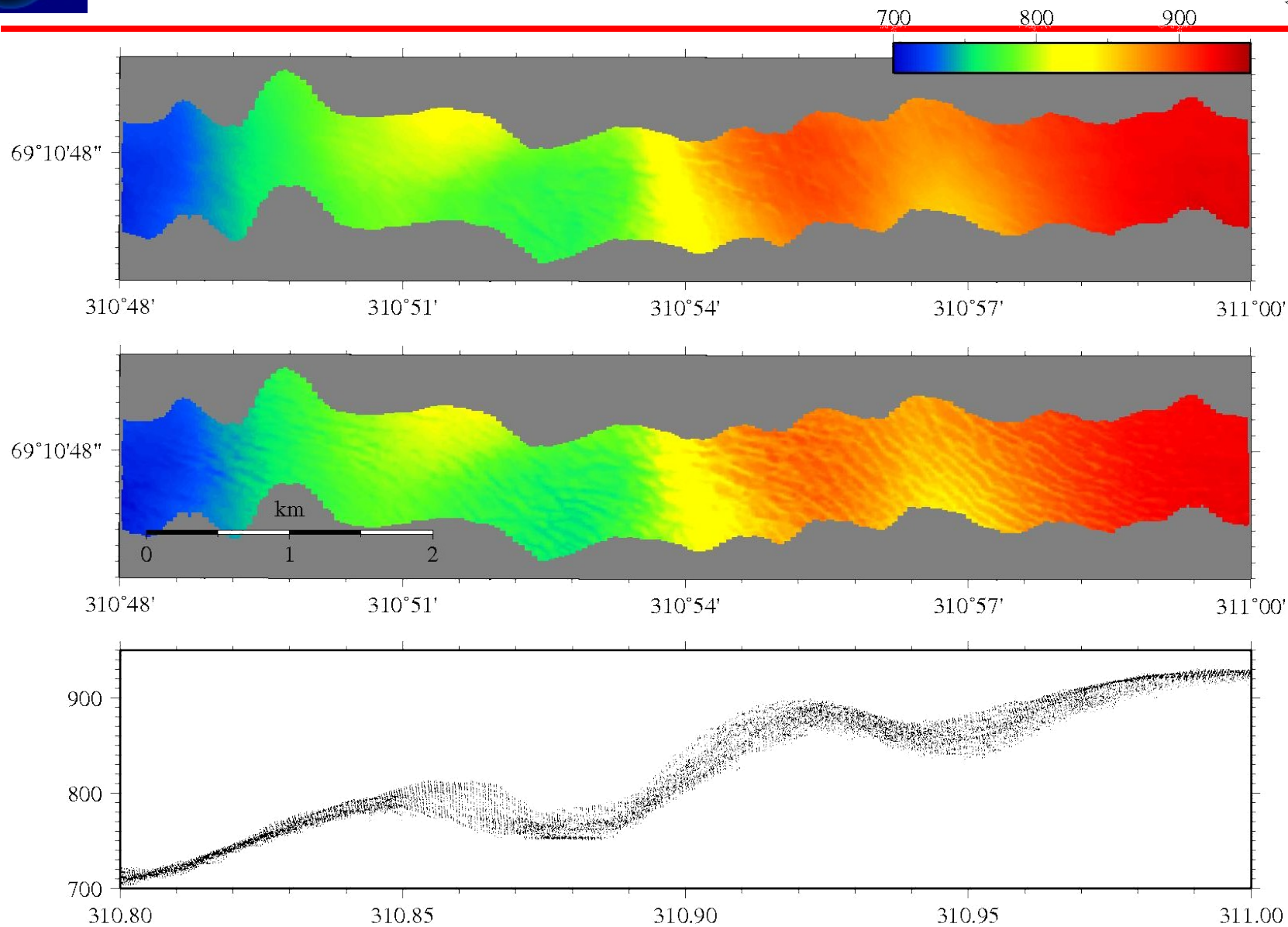
## LVIS '09-'07 elevation differences north of 72N







# Bottom and Top heights over Jakobshavn



84°12'

84°09'

84°06'

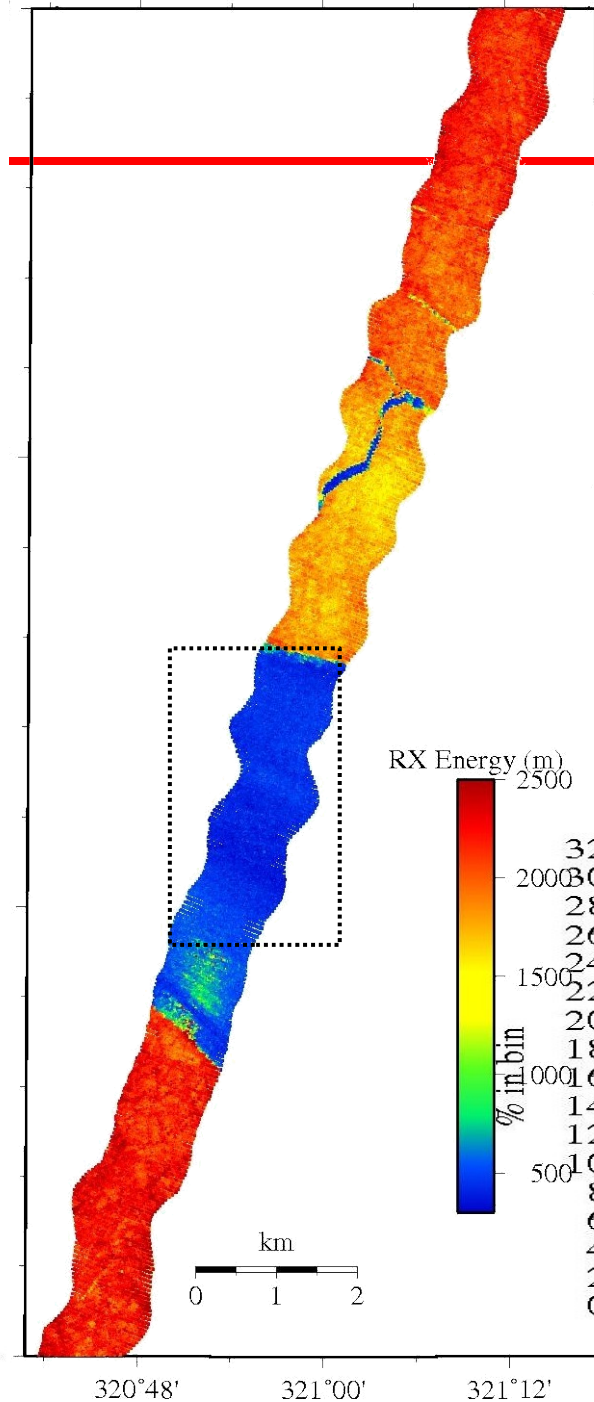
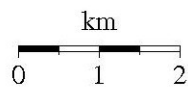
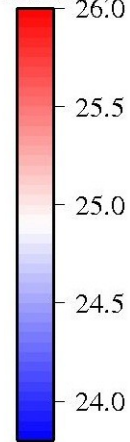
84°03'

320°48'

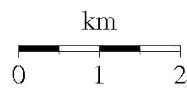
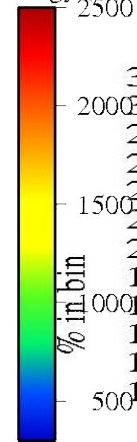
321°00'

321°12'

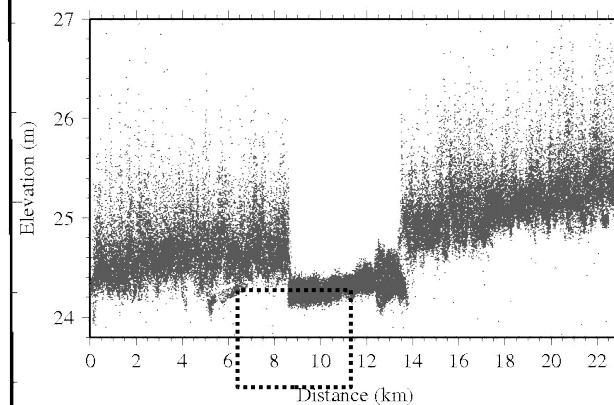
Elevation (m)



RX Energy (m)

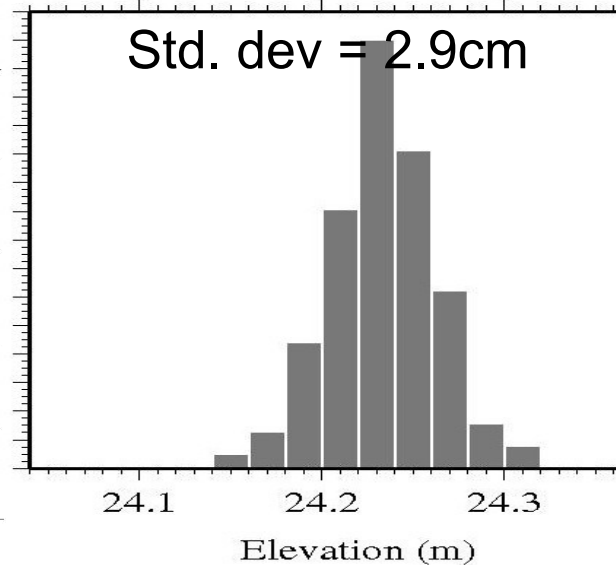


# LVIS Sea Ice Flight April 16 2009



## Elevation of lead

Std. dev = 2.9cm





# LVIS Operation For Antarctica



- **Current flight plans: 2 high altitude flights plus sea ice high altitude transects on sea ice flights**
  - ◆ **LVIS crew (3 people) in Chile for first 2.5 weeks of deployment**
- **Flight parameters: 440 knots, 35,000'+ over continent**
- **No known issues with operating with other instruments**
- **Applanix 610 provides a factor of 2 better performance than our 510. 610 gyro should be mounted on LVIS optical bench. This is critical for achieving the required accuracy from high altitude.**
- **Ground GPS in Chile/Antarctica**
- **Instrument will have a 2.5 km wide swath**





# LVIS Instrument Status



- **Resolved scanner issue experienced in Greenland**
  - ◆ **Grounding problem due to a poor/intermittent ground/shield connection in one of the scanner cables**
  - ◆ **New scanners in hand**
- **Laser controller replaced. Spare laser in fab.**
- **Upgrading digitization rate to 1 Gsamp/sec for improved range precision.**
- **Will be using two detector channels with a 90/10 split of energy and 10-bit digitizers to accommodate large dynamic range variations.**
- **Upgrading receiver scanner mirror and laser rep-rate to increase scan speed to keep up with DC-8 ground speed.**

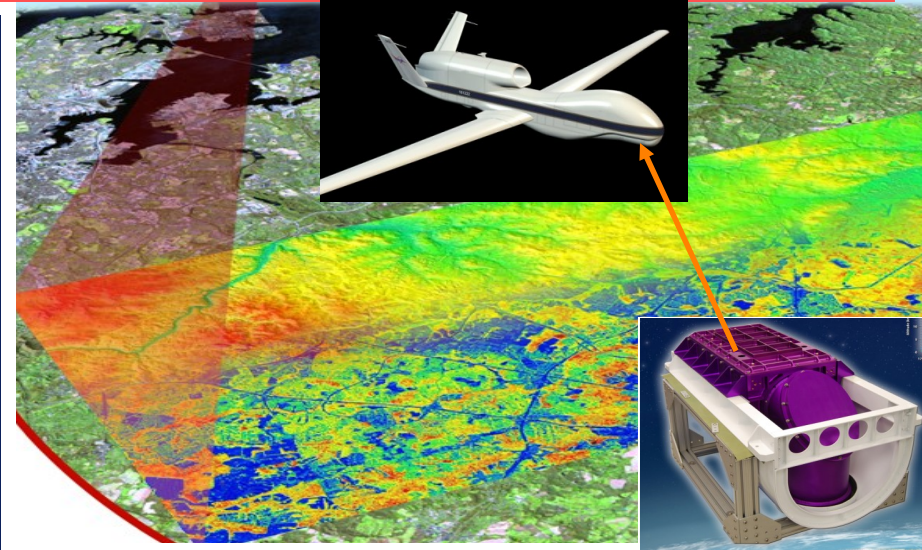


# LVIS: High-altitude Laser Altimetry on the Global Hawk



## Objectives:

- Integrate LVIS capability onto the Global Hawk (GH)
- Update the LVIS design (provides advantages for lower altitude LVIS facility instruments).
- Automate LVIS operations for GH (hands-off, turn-key operations).
- Operational capability and data storage for 30+ hours of GH operations.
- Reliability improvements - improved electrical system design, packaging, thermal control, component testing, ruggedization, housekeeping data collection, performance and health monitoring.



## Approach:

- Repackage LVIS design to fit into existing Cloud Precipitation Lidar (CPL) enclosure on GH
- Optimize receiver for altitude and space constraints
- Updated digitization system
- Automate control and data collection system
- Additional detector to avoid saturation issues
- Bench-top functional checkout
- Perform mechanical and electrical integration and testing at DFRC in the Global Hawk

## Co-Is/Partners

Dryden (DFRC), Northrop Grumman, Sigma Space, Welch Mechanical Design, SSAI

## Key Milestones:

- |                                |              |
|--------------------------------|--------------|
| • Instrument design            | - October 09 |
| • Performance review           | January 10   |
| • Electrical integration on GH | April 10     |
| • Mechanical integration on GH | August 10    |

$TRL_{in} = 5, TRL_{out} = 6$

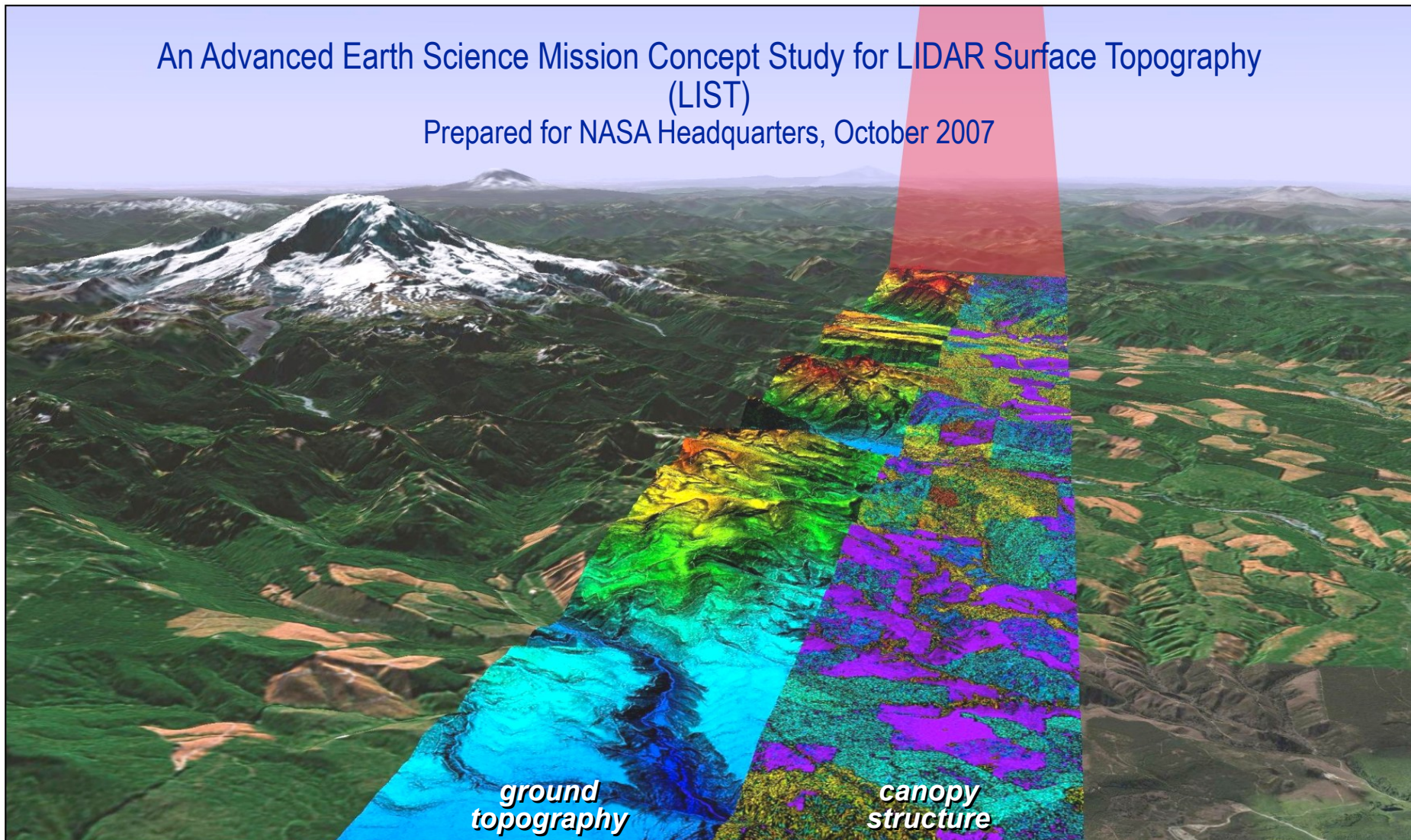




# LIST Mission

An Advanced Earth Science Mission Concept Study for LIDAR Surface Topography (LIST)

Prepared for NASA Headquarters, October 2007



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